DOWNSCALING NASA CLIMATOLOGICAL DATA TO PRODUCE DETAILED CLIMATE ZONE MAPS

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ABSTRACT

The design of energy efficient sustainable buildings is heavily dependent on accurate long-term and near real-time local weather data. To varying degrees the current meteorological networks over the globe have been used to provide these data albeit often from sites far removed from the desired location. The national need is for access to weather and solar resource data accurate enough to use to develop preliminary building designs within a short proposal time limit, usually within 60 days. The NASA Prediction Of Worldwide Energy Resource (POWER) project was established by NASA to provide industry friendly access to globally distributed solar and meteorological data. As a result, the POWER web site (power.larc.nasa.gov) now provides global information on many renewable energy parameters and several buildings-related items but at a relatively coarse resolution. This paper describes a method of downscaling NASA atmospheric assimilation model results to higher resolution and maps those parameters to produce building climate zone maps using estimates of temperature and precipitation. The distribution of climate zones for North America with an emphasis on the Pacific Northwest for just one year shows very good correspondence to the currently defined distribution. The method has the potential to provide a consistent procedure for deriving climate zone information on a global basis that can be assessed for variability and updated more regularly.

1. INTRODUCTION

Historical and near real-time weather data is frequently a requirement by many industries and applications. To varying degrees the current meteorological networks over the globe have been used to provide these data albeit often from sites far removed from the desired location. The design of efficient sustainable buildings is, for example, one industry that is heavily dependent on accurate local weather data. The NASA Prediction Of Worldwide Energy Resource (POWER) project was established by NASA to provide industry friendly access to globally distributed solar and meteorological data. POWER became aware of the buildings industry needs to reduce the time required to obtain weather and solar radiation data for a foreign country, particularly if the location is in a rural, underdeveloped area. The national need is for a quick look at weather and radiation data to develop preliminary building designs within a short proposal time limit, usually within 60 days. Several U.S. and international government agencies have the same requirement. Over the past 10 years, NASA has supplied global data to the World Health Organization, the United Nations, Natural Resources Canada, and two U.S. Department of Energy laboratories. Requests for some buildings- and agricultural-related parameters have also come from private, academic, and commercial users of NASA's Surface meteorology and Solar Energy (SSE) web site (http://eosweb.larc.nasa.gov/sse). As a result, the POWER web site (power.larc.nasa.gov) now provides global information on many renewable energy parameters and several buildings-related items.

The meteorological data sets provided by the POWER and SSE web portals are obtained from global atmospheric assimilation data sets and remapped to the coarse resolution of 1º x 1º. An atmospheric assimilation model forces a global atmospheric circulation with initial conditions from surface, upper air, and satellite measurements. At each time step, those observations are used to optimize global meteorological fields for the next forecast. The resulting

environmental parameters (i.e. temperature, precipitation, etc.) are optimized relative to the observations at the next time step. The processing of a global model in this way is known as a reanalysis. However, the grid scales of the output products from this process are often too coarse for regional to local scale applications. Numerous studies have been published describing various approaches to adjust the parameters values on the models native grid to a more localized grid ([1,2,3]; and refs cited therein). This process is referred to as downscaling. The downscaling methodology employed herein to produce climate zone maps utilizes the temperature estimates from assimilation models developed by NASA's Global Modeling and Assimilation Office (GMAO). The downscaling technique is based upon a statistical calibration of the GMAO modeled temperature through comparison with ground observations which results in a set of lapse rate and offset parameters. These downscaling parameters, coupled with the difference between the reanalysis grid cell and a ground site, can be used to downscale the modeled temperatures to non-sampled ground sites.

New GMAO reanalysis meteorology, referred to as MERRA (Modern Era Retrospective analysis for Research and Applications, [4]), with 2/3 degree longitude x 1/2 degree latitude spatial resolution is now undergoing validation tests. Initial results indicate improved accuracy over previous reanalysis models products having results produced on a 1^{o} x 1^{o} resolution. Since building design needs often require higher resolution, a lapse rate/offset analysis is being performed to downscale the data products to a 10-minute longitude/latitude grid (or about 18 x 18 km at the equator), based on elevation differences within the targeted spatial grid. The higher spatial resolution should allow individual users to apply lapse rate adjustments that are more appropriate for their particular geographical region.

2. PRESENT SITUATION

The original DOE/ASHRAE buildings climate zone map is based on cluster analysis for United States counties using 1961 - 1990 NCDC SAMPSON ground-site data from 230 sites (figure 1). The method assumes constant-height topography within each county according to [5]. Table 1 describes the characteristics of the climate zones. ASHRAE Standard 90.1-2004 ([6]) continued to use the same climate zone classifications and map. Within-county elevation differences remain unresolved in the current DOE/ASHRAE county energy codes.

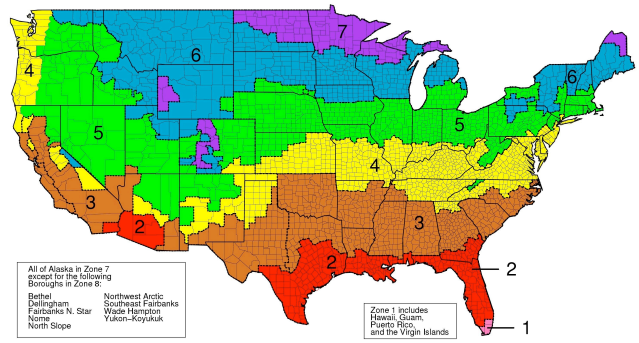

Fig 1. Briggs *et al.* (2002) Climate Zones for the Unites States

Table 1. Characteristics of Briggs *et al.* (2002) buildings climate zones

Zone #	**Climate Zone Name & Type**	**Zone #**	**Climate Zone Name & Type**
1A	Very Hot – Humid	5A	Cool – Humid
1B	Very Hot – Dry	5B	Cool – Dry
2A	Hot – Humid	5C	Cool – Marine
2B	Hot – Dry	6A	Cold – Humid
3A	Warm – Humid	6B	Cold – Dry
3B	Warm – Dry	7	Very Cold
3C	Warm – Marine	8	Subarctic
4A	Mixed – Humid		
4B	Mixed – Dry		
4C	Mixed – Marine		

3. NEW APPROACH

The POWER project has analyzed the use of NASA data sets to produce climate zone maps for the United States and the entire globe by using the method summarized in table 2A and 2B of [5]. POWER's first endeavor used NASA's Global Modeling and Assimilation Office (GMAO) Goddard Earth Observing System (GEOS) Data Assimilation System - Version 4. The native grid of GEOS-4 is 1.25 x 1 degrees of longitude and latitude. Daily average, minimum and maximum air temperature was re-gridded to 1 x 1 degrees of longitude and latitude. 22-years of data from July 1983 through June 2005 were used to calculate monthly average/minimum/maximum temperature and annual sums of heating and cooling degree days. The Global Precipitation Climatology Project (GPCP) precipitation data was used in conjunction with the GEOS-4 temperature data to classify dry, humid and marine environments. The resulting climate zone map is shown in figure 2. The available data provided a means to expand the climate zone maps beyond the United States and cover the entire globe.

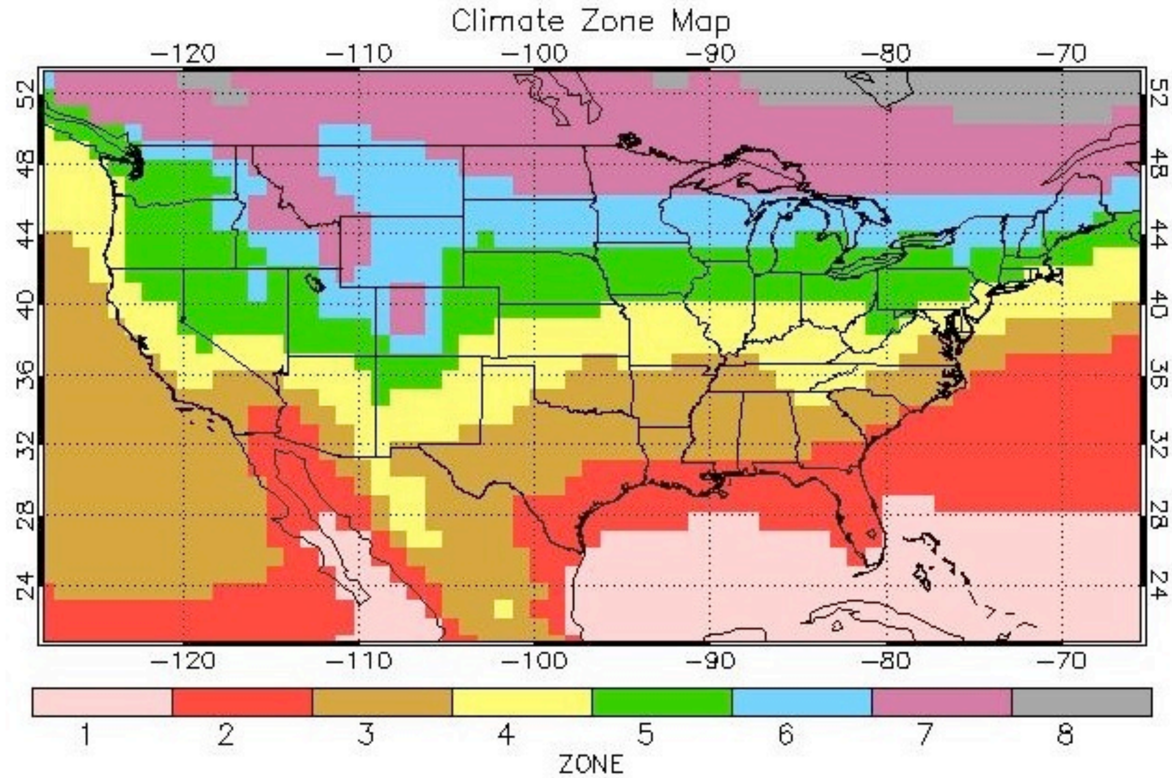

Fig 2. Climate zone map derived from NASA 1-degree data

4. DOWNSCALING TO HIGHER RESOLUTION

The elevation differences within United States counties (the spatial resolution of the current DOE/ASHRAE climate zones) and within 1-degree grids (first approach using NASA data) prompted POWER to evaluate methods of downscaling NASA temperature data to 10-minute grid cells. The average elevation has been determined for both spatial scales (1-degree and 10-minute) from the United States Geological Survey (USGS) Global 30 Arc-Second Elevation Data Set (GTOPO30). A map of the higher resolution data is shown in figure 3.

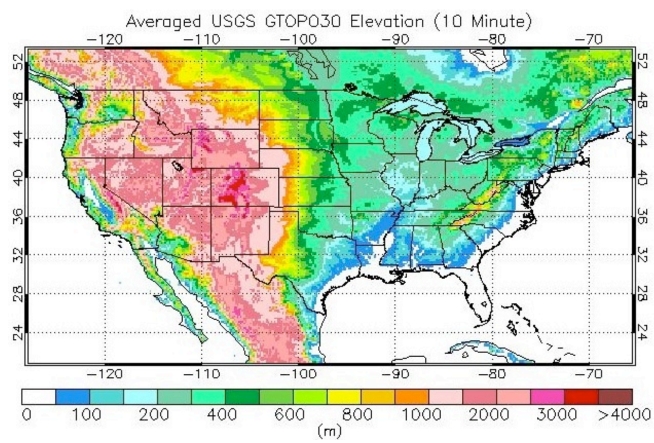

Fig 3. Elevation map derived from USGS GTOPO30 data averaged to 10-minute

POWER has developed a correction procedure that can be used to spatially 'downscale' temperature fields from NASA's reanalysis. We note that our original proof-of-concept analysis used the NASA reanalysis model designated as GEOS-4, which has a 1-degree grid cell. Our downscaling approach is based upon the use of lapse rates derived through "calibration" of the NASA model values to observations from a local or regional ground site

network. These lapse rates along with model bias are used to adjust the model temperatures to local ground site values. Lapse rate adjustments were determined for the GEOS-4 1-degree data and subsequent 10-minute longitude/latitude climate zone maps were produced.

POWER has now developed improvements by using higher resolution NASA data and lapse rate adjustments to downscale to a spatial resolution of 10 minutes of longitude/latitude. The new approach employs the MERRA reanalysis modeled 2/3 x 1/2 degree longitude/latitude temperature data which is then adjusted (lapse rate and offset) using elevation data on a 10-minute scale derived from the United States Geological Survey (USGS) GTOPO-30 dataset. The result is MERRA temperature data downscaled to 10-minute resolution.

Our downscaling approach is based upon a linear relationship that exists between the elevation difference of the GMAO reanalysis model grid and surface station elevation. Data plots are shown for January and July 2004 in figures 4a and 4b, respectively. Using this relationship between the elevation difference and bias, a lapse rate and offset adjustment, determined by the slope and intercept of the linear trend line, can be determined for each temperature parameter (figure 5). Applying the lapse rate and offset adjustment back to the model temperature, we see better agreement between the model temperature and surface station temperature in the form of a much smaller bias.

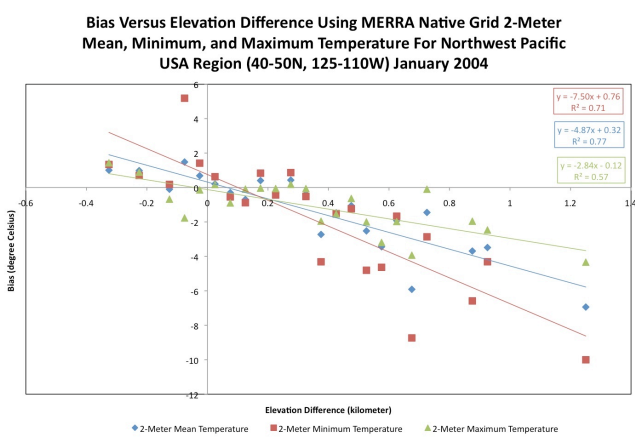

Fig 4a. Elevation difference and bias analysis for January 2004

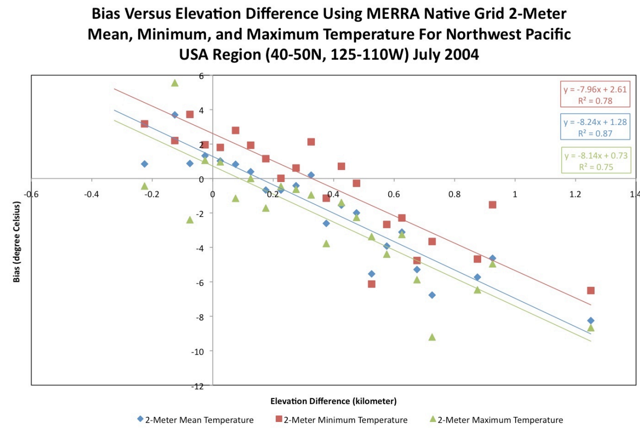

Fig 4b. Elevation difference and bias analysis for July 2004

Downscaling Parameters

$$\Delta T = \lambda * \Delta H + \beta$$

Scatter plot of Bias vs ElevDiff

λ = Slope = Lapse Rate **β = Intercept = Offset**

Downscaled Reanalysis Temperature

$$(T_{ds}) = (T_{nat}) + \lambda * (H_{grd} - H_{nat}) + \beta$$

Where:

T_{ds} is downscaled reanalysis temperature
T_{nat} is native reanalysis grid temperature
H_{grd} is ground [localized] elevation
H_{nat} is native reanalysis grid elevation

Fig 5. Downscaling parameters and equations

The initial study area was the Pacific Northwest region of the United States, which was chosen because it has a complex topography consisting of coasts, mountains, and plains. The lapse rate adjusted values are an estimated temperature at two meters above the surface within the 10-minute longitude/latitude cell. These new high spatial resolution temperatures have been compared with National Climate Data Center (NCDC) ground-site measured temperatures. Temperature, heating degree day, and cooling degree day estimates for the MERRA native grid and lapse rate adjusted 10-minute grid are shown in figure 6 for the Pacific Northwest.

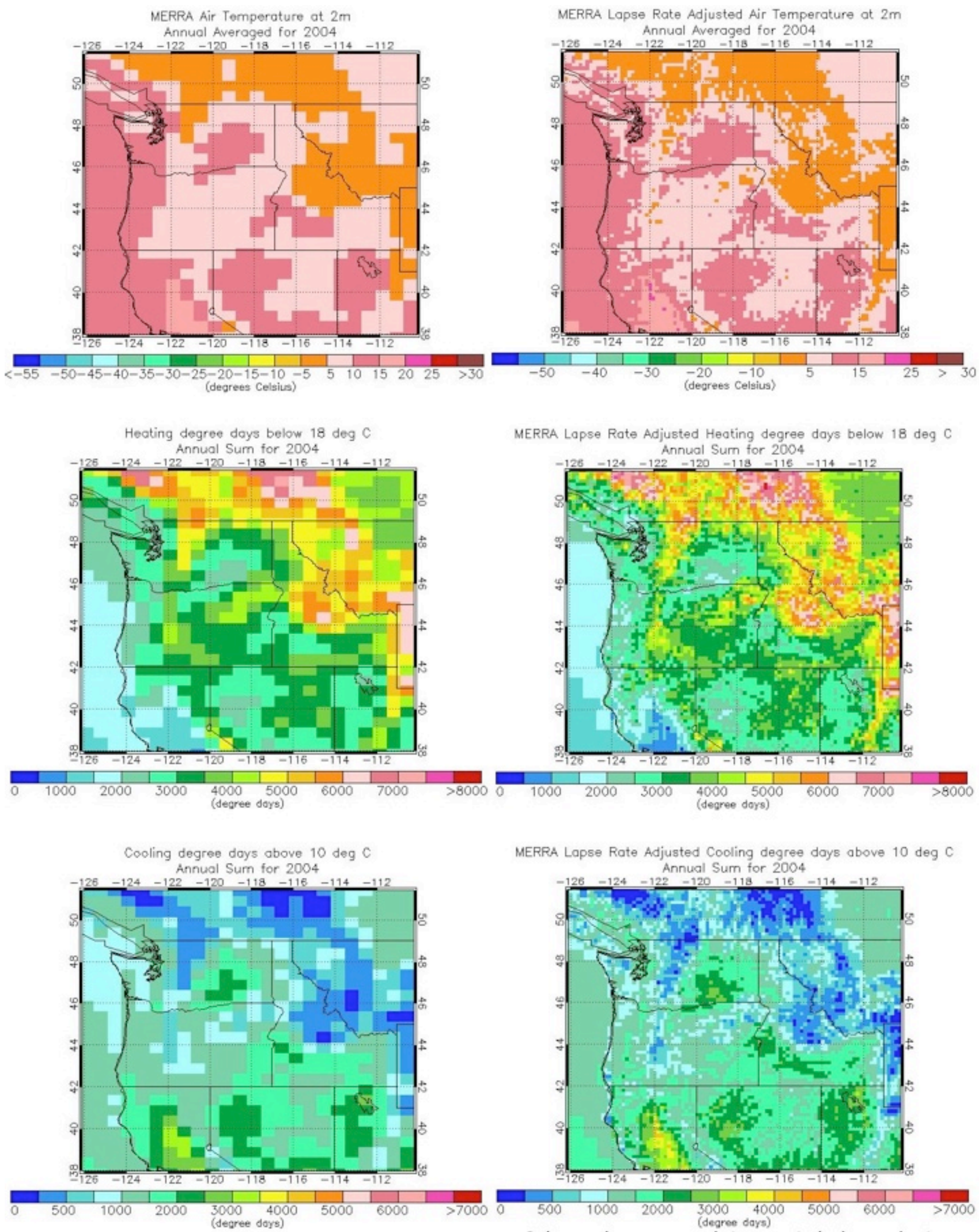

Fig 6. Temperature, heating degree day, and cooling degree day estimates for the MERRA native grid and lapse rate adjusted 10-minute grid

Monthly averaged precipitation and air temperature are used to determine climate type (dry, humid, marine), which is then used to calculate climate zones. Throughout our analysis, precipitation data has been used from two sources: GPCP and MERRA data sets. The native grids of GPCP and MERRA are 2.5 x 2.5 and 2/3 x 1/2 degree, respectively. These data sets have been downscaled to 1-degree (GPCP) and 10-minute (GPCP, MERRA) by replication (figure 7). It can be noted that precipitation has

a very minor influence on the climate type calculation, and hence, the climate zone calculation.

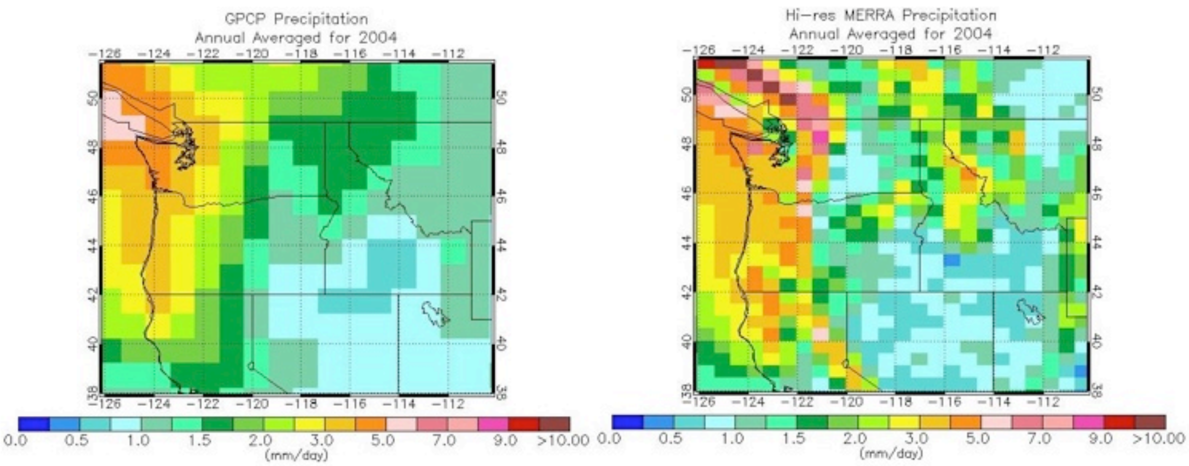

Fig 7. Precipitation: GPCP rescaled to 1-degree and MERRA rescaled to 10-minute

The downscaled MERRA temperature values subsequently provide heating and cooling degree day values which are used to map DOE/ASHRAE-type building climate zones over the entire globe on a 10-minute longitude/latitude scale (figure 8). More detail in coastal and mountain topography has been achieved by downscaling the higher resolution NASA data as compared to the presently available DOE climate zones and the 1-degree NASA data.

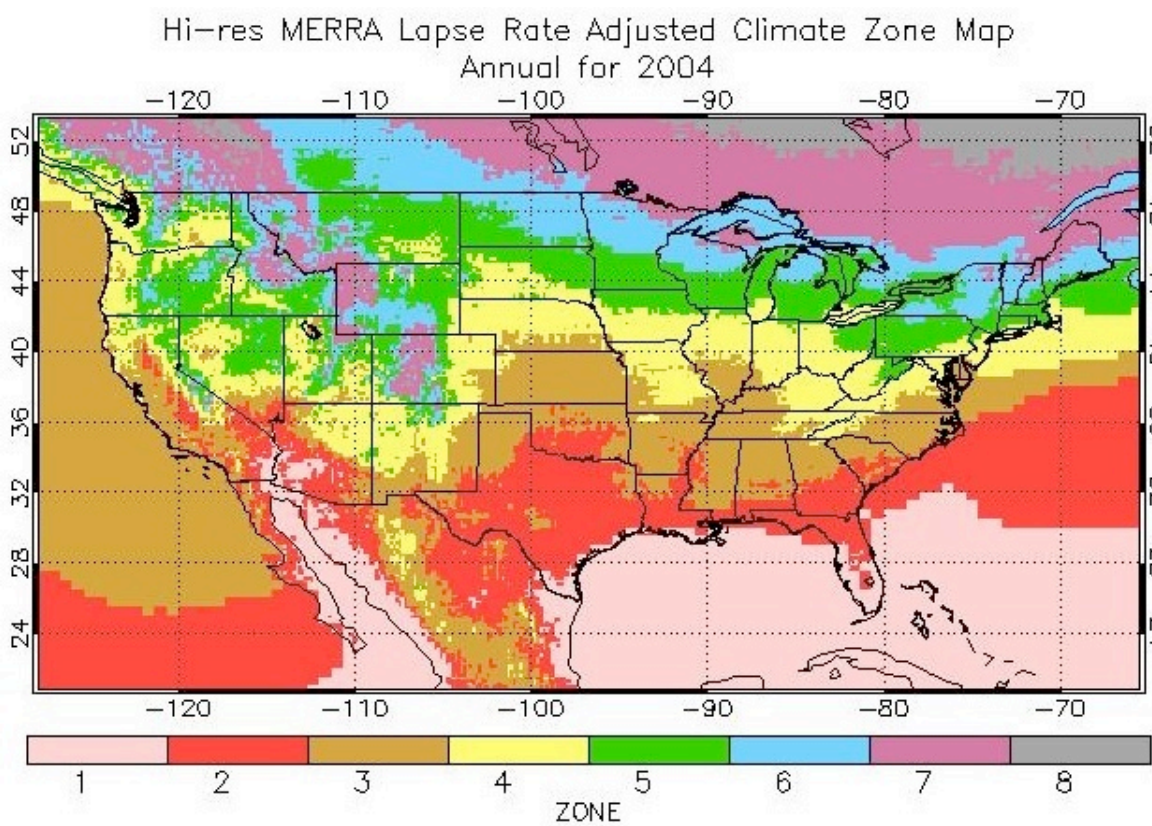

Fig 8. Climate zone map derived from NASA MERRA data downscaled to 10-minute

5. FUTURE

This paper described initial results in estimating both near-surface (i.e. 2-m) temperatures and DOE/ASHRAE-type climate zones on a 10-minute grid system over the entire globe. Following this initial analysis based on MERRA data for the year 2004 and lapse rate analysis for the Pacific Northwest region of the United States, the time period will be extended to include more than 25 years of NASA data and global or regional lapse rate adjustments.

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References

(1) Kostopoulou1, E., C. Giannakopoulos, C. Anagnostopoulou2, K. Tolika, P. Maheras, M. Vafiadis, and D. Founda, 2007: Simulating maximum and minimum temperature over Greece: a comparison of three downscaling techniques. Theor. Appl. Climatol. 90, 65–82 (2007)

(2) Wood, A. W., Leung, L. 5 R., Sridhar, V., and Lettenmaier, D. P.: Hydrologic implications of dynamical and statistical approaches to downscaling climate model outputs, Climatic Change, 62, 189–216, 2004.

(3) Maurer, E.P., J.C. Adam, and A.W. Wood: Climate Model based consensus on the hydrologic impacts of climate change to the Rio Lempa basin of Central America, Hydrology and Earth System Sciences 13, 183-194, 2009.

(4) Bosilovich, M. 2008. NASA's Modern Era Retrospective-analysis for Research and Applications: Integrating Earth Observations. Earthzine

(5) Briggs, Robert S., R. G. Lucas, Z. T. Taylor, 2002: Climate Classification for Building Energy Codes and Standards. Technical Paper, Pacific NW National Laboratory, March 26, 2002 (http://www.energycodes.gov/implement/pdfs/climate_paper_review_draft_rev.pdf)

(6) ANSI/ASHRAE/IESNA Standard 90.1-2004, Energy Standard for Buildings Except Low-Rise Residential Buildings, U. S. Department of Energy Building Energy Codes Program